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(54) IMPROVEMENTS IN WINDMILL GENERATION OF ELECTRICITY

SPECIFICATION NO 1514995

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By a direction given under Section 17 (1) of the Patents Act 1949 this application proceeded in the name of SIR HENRY LAWSON-TANCRED, SONS & COMPANY LIMITED, of Aldborough Manor, Boroughbridge, Yorkshire, a British Company.

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that without storing the power generated at irregular and mostly relatively low levels, a wind generator of economic size is scarcely ever able to meet the maximum demand on it. And of course storage of electrical energy is in itself problematical and expensive. On the other hand, the albeit infrequent occurrence of high winds requires special measures to protect the installation, largely because the electric generator, if it is designed for average wind conditions, cannot absorb the very much higher power levels in high winds. The power output of a wind wheel can be proportional to the *cube* of the wind speed. Largely on account of this fact, windmills have been designed which accommodate higher-than-average winds speeds by a loss of efficiency—the so-called Cretan windmill, with fabric sails that flap and lose lift at higher wind speeds is an example in which the speed limitation is inherent in the design. Other types of wind wheel have mechanism, which can be automatic, for adjusting the angle of attack of the blades, and, of course, the friction brake is most often resorted to. Using a generator sufficiently large to absorb high wind power such as is only infrequently encountered would involve high capital costs, and incur heavy losses due to the inefficiency of the generator at the lower, average speeds.

Wind generators, for example for domestic purposes, have a further disadvantage in that

[illegible] electric power generation in which energy obtained from the wind is accumulated and used to drive electric generator means at substantially constant power only when the amount of accumulated energy exceeds a predetermined value.

A single generator may be driven at a predetermined substantially constant power level when the accumulated energy exceeds said predetermined value, or one or both of two generators may be driven each at a substantially constant power level according as the level of accumulated energy exceeds different predetermined values. Said two generators may have different outputs, and the lower output generator be driven when the accumulated energy is at a second, higher level.

In this way, the generator or generators may be operated at rated speed and thus with maximum efficiency. The generator operates, of course, intermittently at low wind speeds, so long as there is wind enough to turn the wind wheel, and the periods in which it generates increase with increasing wind speed until it is generating continuously. If there are two generators, when the wind speed exceeds that required to keep the first generator running, excess power is accumulated for the second generator which then runs intermittently, but for increasingly long periods as the wind speed increases further. When the wind energy exceeds the capacity

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(54) IMPROVEMENTS IN WINDMILL GENERATION OF ELECTRICITY

(71) I, Sir HENRY LAWSON-TANCRED, Bart., of Aldborough Manor, Boroughbridge, Yorkshire, a British subject, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the generation of electric power from wind energy.

There is a multiplicity of problems connected with the use of wind energy for power generation. The variable nature of wind, and the relative infrequency of adequately strong winds in preferred areas of habitation mean that without storing the power generated at irregular and mostly relatively low levels, a wind generator of economic size is scarcely ever able to meet the maximum demand on it. And of course storage of electrical energy is in itself problematical and expensive. On the other hand, the albeit infrequent occurrence of high winds requires special measures to protect the installation, largely because the electric generator, if it is designed for average wind conditions, cannot absorb the very much higher power levels in high winds. The power output of a wind wheel can be proportional to the *cube* of the wind speed. Largely on account of this fact, windmills have been designed which accommodate higher-than-average winds speeds by a loss of efficiency—the so-called Cretan windmill, with fabric sails that flap and lose lift at higher wind speeds is an example in which the speed limitation is inherent in the design. Other types of wind wheel have mechanism, which can be automatic, for adjusting the angle of attack of the blades, and, of course, the friction brake is most often resorted to. Using a generator sufficiently large to absorb high wind power such as is only infrequently encountered would involve high capital costs, and incur heavy losses due to the inefficiency of the generator at the lower, average speeds.

Wind generators, for example for domestic purposes, have a further disadvantage in that they must be kept quite separate from the mains supply, so that the mains power cannot be used to supplement the wind generator power during high local demand periods or periods of low wind, nor, without expensive phase and voltage matching equipment, can they be used to feed back into the mains ("selling" electricity back to the power station) when local demand does not absorb the entire wind generated supply.

The present invention provides a method and apparatus for wind power generation in which this last mentioned disadvantage can be eliminated, and in which many other disadvantages are avoided or substantially reduced.

The invention comprises a method for electric power generation in which energy obtained from the wind is accumulated and used to drive electric generator means at substantially constant power only when the amount of accumulated energy exceeds a predetermined value.

A single generator may be driven at a predetermined substantially constant power level when the accumulated energy exceeds said predetermined value, or one or both of two generators may be driven each at a substantially constant power level according as the level of accumulated energy exceeds different predetermined values. Said two generators may have different outputs, and the lower output generator be driven when the accumulated energy is at a second, higher level.

In this way, the generator or generators may be operated at rated speed and thus with maximum efficiency. The generator operates, of course, intermittently at low wind speeds, so long as there is wind enough to turn the wind wheel, and the periods in which it generates increase with increasing wind speed until it is generating continuously. If there are two generators, when the wind speed exceeds that required to keep the first generator running, excess power is accumulated for the second generator which then runs intermittently, but for increasingly long periods as the wind speed increases further. When the wind energy exceeds the capacity of the generator means, excess energy can be dumped. This, of course, introduces a meas-

ure of inefficiency for which prior art windmills are criticised above. However, in this regard there is an important distinction from the prior art methods in that prior art generators had to be specified for average wind conditions, whereas with the invention the generator means can be specified to work efficiently at much higher wind speeds, so that it becomes necessary to envisage energy dumping only on rare occasions.

Preferably, the generator means comprise an induction machine. Because it operates, when it does operate, at constant power, which is to say constant revolutions, it can be matched for voltage and frequency to the mains supply to be energised thereby and even to feed electrical energy thereinto when its constant power output exceeds local demand, but to allow local demand to be supplied from the mains supply when the induction machine is not driven from the accumulated energy or when the local demand exceeds its constant power output. The generator will be forced into phase alignment with the mains supply, and the phase and voltage matching equipment mentioned above is not required.

The generator means may be driven by hydraulic motor means. In this case, the wind energy may be accumulated in intermediate hydraulic form in a loaded, for example gravity loaded, piston-in-cylinder arrangement. The position of the piston in the cylinder may control, for example through limit switches, the operation of the generator means by controlling the supply of hydraulic fluid to the hydraulic motor means. The fluid is pumped into the cylinder by the rotation of the wind wheel. The pressure is determined essentially by the gravity loading on the piston, and the higher the piston level, the more energy is stored in intermediate hydraulic form in the cylinder.

The windwheel may be a fixed pitch wheel driving hydraulic gear pump means of which the torque is arranged to be at least roughly proportional to the square of the wind wheel revolutions. In this way, the fixed pitch wheel can operate at substantially maximum efficiency over the whole of a wide speed range. By virtue of the accumulation of energy in intermediate form, so that the wind wheel does not drive the generator means directly, there is no limitation on wheel speed from the point of view of optimum or maximum generator revlutions or to keep the generator output in synchronism with the mains supply.

A single gear pump has a torque proportional to speed, and would not, on its own, effect the desired relationship. However, a plurality of pumps may be equipped with by-pass means rendered progressively inoperative as wheel speed increases, to give an approximation to the desired relationship. For example, there may be four such similar pumps driven by the wheel at substantially equal speeds, of which three are by-passed (so as to run at substantially zero torque) at a first wind wheel speed at the lower end of a given speed range, and none is by-passed at a second wind wheel speed approximately twice the first speed at the upper end of said speed range. At the second speed, therefore, the power absorbed by the pumps will be eight times that at the said first speed, because each of the pumps is absorbing twice as much power as the single pump not by-passed at the first speed. Appropriate selection of the intermediate speeds at which the by-passes on two of the four gear pumps cut in and out will thus substantially match the wind wheel output power to the power the gear pumps can absorb, and give a highly efficient arrangement in which wheel speed approximates very closely to the optimum speed for all conditions across the chosen speed range.

Of course it may be desirable to have a speed range in which the maximum speed is greater than twice the minimum speed, and this will be accommodated by having some planned loss of efficiency at the very lowest speeds, and by the provision of an excess energy dumping arrangement at the higher end of the range. The energy may be dumped in the intermediate form as by flow of hydraulic fluid through a restricted orifice, which can be controlled by a bleed-off valve actuated by a limit switch on the piston-in-cylinder arrangement.

The invention also comprises apparatus for use in electric power generation from wind energy comprising an accumulator for said wind energy in an intermediate form connectible to drive electric generator means, and control means for connecting said accumulator to drive said generator when the amount of accumulated energy exceeds a predetermined value.

Said accumulator may comprise an hydraulic piston-in-cylinder arrangement, which may be gravity loaded, so that its output pressure is substantially constant, and the apparatus may comprise piston-position controlled hydraulic motor means driving said generator means.

The apparatus may comprise control means comprising four limit switch means actuating control valves for a low power hydraulic motor, a high power hydraulic motor and a hydraulic energy dumper so that at a first position, the motors and the energy dumper are inoperative, and as the piston ascends, first the first motor then the second motor then finally the energy dumper are brought into action, and as the piston descends, first the energy dumper, then the second motor and finally the first motor are shut down. Of course, the normal operating condition will be that either the first motor

is cycled on and off, with the second motor and energy dumper inoperative, or the first motor is continuously running while the second motor cycles on and off. In high wind conditions, both motors will be running continuously, with the energy dumper operating at intervals.

The apparatus may also comprise wind wheel driven hydraulic pump means connected to said piston-in-cylinder arrangement. Said pump means preferably have a torque at least roughly proportional to the square of the wind wheel speed.

Said pump means may comprise a plurality of gear pumps and by-pass means operable in accordance with the wind wheel speed so that at low wheel speeds only one pump is on torque, but at progressively higher speeds, other pumps are brought on torque. The apparatus may comprise four similar gear pumps of which three have by-pass valves and control means arranged to close the by-pass valves serially at progressively higher wind wheel speeds such that all three are closed at about twice the speed at which all three are open.

The apparatus may also comprise a wind wheel, which may be a fixed pitch wind wheel driving the hydraulic pump means through step up gearing if desired. Support means for the wheel may be provided arranged automatically to orientate the wheel into the wind.

The wheel may comprise flaps or spoilers and means automatically to extend or deploy the same to limit wheel revolutions in unusually high winds. The apparatus may also comprise a brake and automatic means to apply the brake when the wind speed exceeds a predetermined limit of safety for the wheel or supporting structure.

The apparatus may also comprise a mains energised induction generator adapted to be driven from said accumulator in frequency and voltage alignment with the mains supply so that it can feed electrical energy to or draw electrical energy from the mains supply according to the varying demands of a local load. A convenient capacity for said mains energised generator is about five kilowatts.

The apparatus may also comprise a self energised generator, which may be of about 25—30 KW capacity. Such generator may be used with a smaller mains energised generator so as to provide a comprehensive energy supply for domestic purposes, the larger generator being connected to a resistive load for heating, for example water heating or central heating, and the smaller generator supplying power for low current requirements such as refrigerator, freezer, lighting and so on, in parallel with the mains supply.

Alternatively, a single large, say 30Kw three phase generator can be used in circumstances where it is possible to feed back so much power into the mains.

One embodiment of a method and apparatus for electric power generation from wind energy will now be described with reference to the accompanying drawings in which the single Figure is a diagrammatic illustration of apparatus for providing up to 30KW of power from a 60 ft (18 metre) diameter wind wheel.

The apparatus comprises a three bladed fixed pitch wind wheel 11 on a support structure in which the blade shaft 12 is mounted on a vertical post 14 so that it can be faced into the wind by a tail fin 15. The wheel 11 drives through step up gearing 16 an hydraulic pump arrangement 17 comprising four hydraulic gear pumps 17*a*, 17*b*, 17*c*, 17*d*. A shaft speed transducer 18 controls by-passes on three of the pumps so that at low shaft speeds only one pump, say pump 17*a*, is on torque, but at high shaft speeds all four pumps are on torque and at intermediate speeds pumps 17*b* and 17*c* are brought on torque so that the torque of the gear pump arrangement increases approximately according to the square of the shaft speed. It may well be arranged for example that at a wind speed of 10 mph (16 kph) the pump 17*a* only is on torque, but at 20 mph (32 kph) all four pumps are on torque. Shaft speed will then be double, at 20 mph what it is at 10 mph, and the total power absorbed by the gear pumps at 20 mph wind speed will be eight times what it is at 10 mph wind speed. The power output of a fixed pitch wind wheel whose tip speed is proportional to wind speed—the condition for maximum efficiency over the operating range—is proportional to the cube of the wind speed. So the gear pump arrangement 17 already matches the fixed pitch wind wheel and allows substantially maximum efficiency operation across the whole speed range.

The pump arrangement 17 draws hydraulic fluid from a header tank 19 and delivers it under constant pressure to the bottom of a cylinder 21 in which works a piston 22 gravity loaded by a ballast weight 23 which in fact determines the said constant pressure. The fluid passes out of the cylinder to drive hydraulic motors 24, 25 according as associated control valves 24*a*, 25*a* are open or closed.

If the pump arrangement delivers more fluid to the cylinder 21 than passes out to drive the motors 24, 25, then the piston 22 will rise in the cylinder 21. The movements of the piston 22 in the cylinder 21 control the valves 24*a*, 25*a* through limit switches 26, 27, 28, 29. When the piston rises to trip limit switch 27, valve 24*a* is opened to allow hydraulic pressure to the motor 24, which is a 5KW hydraulic motor driving a 5KW induction generator 31, which is mains energised.

If the rate at which the fluid leaves the cylinder 21 is greater than the rate at which the pump arrangement 17 supplies fluid to the cylinder, the piston 22 will fall again and will actuate limit switch 26 to close the valve *24a*, allowing the piston again to rise. In the meantime, however, the motor 24 will have been driven at such constant pressure as is necessary to drive the induction generator 31 at its rated speed. While the motor 24 is shut down, the pump arrangement 17 will, so long as the wind turns the wind wheel 11, accumulate hydraulic fluid in the cylinder 21 elevating the piston until it again trips limit switch 27 to open valve *24a* to actuate motor 24 once again. Thus at low wind speeds, the wind energy will be accumulated as hydraulic fluid under constant pressure in the cylinder 21, the system actuating motor 24 intermittently, but at constant pressure and therefore maximum efficiency.

The higher the wind speed, the longer will be the periods for which the motor drives the generator 31. At a certain wind speed, the output of the pump arrangement 17 will exceed the consumption of the motor 24, and the piston will rise further because of the continued accumulation of fluid in the cylinder 21. The generator 31 will then be operating continuously. If the piston continues to rise, it will actuate switch 28, which does not affect valve *24a* so that the motor 24 and generator 31 continue to operate, but which opens valve *25a* so that the hydraulic motor 25 operates. This motor 25 drives a self energised induction generator 32 connected to a resistive load 33 for heating purposes. This generator 32 can be a 25 KW generator which is driven at its rated speed and therefore, again, maximum efficiency.

At intermediate wind speeds, the piston 22 will rise and fall in the cylinder 21 between the position at which switch 28 opens valve *25a* and the position at which switch 27 closes the same, so that the motor 25 is operated intermittently, as was the motor 24 at lower wind speeds. When the wind speed is high enough, however, the motor 25 will also rotate the generator 32 continuously.

At higher wind speeds still, the pump arrangement 17 will supply even more fluid to the cylinder 21 than will be taken by the motors 24, 25 operating continuously. Matters are preferably so arranged that this happens only infrequently, but it is still possible to operate the system by providing a further limit switch 29 to open a bleed off valve 34 allowing the excess fluid to be dumped back to the header tank 19 through an energy-dissipating hydraulic orifice 35.

At these higher wind speeds it is also possible to control the supply of energy to the accumulator by automatically extending or deployed flaps or spoilers on the blades of the wind wheel 11, limiting the speed thereof. This of course entails some loss of efficiency, but again it can be arranged to be necessary only at infrequently high wind speeds.

At very high wind speeds, or in the event of a malfunction, or for maintenance purposes, it will be necessary to stop the operation of the apparatus altogether, and brakes 36 are provided in the pump drive which can be operated manually or automatically from the speed transducer 18 in the event of overspeeding or by another safety circuit in the event of other malfunction.

The 5 KW mains energised induction generator 31 can be connected directly to the mains whereby to feed power thereto (through the consumption meter, driving it in reverse, and thereby "selling" power back to the power station) whenever a locally connected load consumes less than the constant (but intermittent) 5KW output, because the generator can be run at synchronous speed with the mains and at an equal output voltage, and no power factor problems arise. Of course, when the wind speed is inadequate to generate enough power to satisfy local demands, this is made up from the mains supply. When the apparatus is connected in this way to the mains supply, however, automatic means should be provided to actuate the brake and isolate the system in the event of a mains failure.

A single 30 KW generator could be connected to the mains supply in the same way. However, it is to be supposed that a 60 ft diameter wind wheel such as would be required to generate this order of power would find its principle application in country districts, where the local mains network might not be so large as comfortably to absorb such an amount of power.

Any desired type of generator can be used. For some applications a synchronous generator might be preferred, for others a d.c. generator might be more appropriate. Alternating current generators can of course be single phase or three phase.

The accumulator means may comprise more than one piston-in-cylinder arrangement—for example, for the construction of wind generators of different sizes, but using standard size parts, two or more cylinders can be connected together in parallel or in series according as a small number of larger generators or a larger number of smaller generators of increasing capacity are to be driven.

There is, of course, no need to operate connected to the mains. The wind generator can be used to store power in batteries or otherwise, or to generate heat and store it in insulated underground tanks for use in conjunction with a heat pump or other central heating arrangement, or possibly to effect a chemical reaction such as the electrolysis of

water to produce combustible hydrogen gas. Wind wheels of different sizes can be constructed with suitable accumulator and generator means and connected in different ways to different types of load. The ability to operate the generator means at optimum efficiency regardless of wind conditions by means of the inventive method and apparatus brings a new level of efficiency to wind power generation, which extends the usefulness of wind wheels as sources of energy.

WHAT I CLAIM IS:—

1. A method for electric power generation in which energy obtained from the wind is accumulated and used to drive electric generator means at substantially constant power only while the amount of accumulated energy exceeds a predetermined value.

2. A method according to Claim 1, in which a single generator is driven at a predetermined substantially constant power level when the accumulated energy exceeds said predetermined value.

3. A method according to Claim 1, in which one or both of two generators are driven each at a substantially constant power level according as the accumulated energy exceeds different predetermined values.

4. A method according to Claim 3, in which the two generators are of different outputs, and the lower output generator only is driven when the accumulated energy is at a first, lower level, and the higher output generator is driven when the accumulated energy is at a second, higher level.

5. A method according to any one of Claims 1 to 4, in which the generator means comprise an induction machine.

6. A method according to Claim 5, in which the said induction machine is connected to the mains supply and a local load so as to feed energy into the mains supply when its constant power output exceeds local demand, but to allow local demand to be supplied from the mains supply when the induction machine is not driven from the accumulated energy or when local demand exceeds the said constant power output.

7. A method according to any one of Claims 1 to 6, in which the generator means are driven by hydraulic motor means.

8. A method according to Claim 7, in which the wind energy is accumulated in a loaded, for example gravity loaded, piston-in-cylinder arrangement.

9. A method according to Claim 8, in which the movements of the piston in the cylinder control the operation of the said generator means.

10. A method according to any one of Claims 1 to 9, in which a fixed pitch wind wheel drives hydraulic pump means of which the torque is arranged to be at least roughly proportional to the square of the wind wheel rotational speed.

11. A method according to Claim 10, in which the wind wheel drives a plurality of hydraulic pumps equipped with by-pass means rendered progressively inoperative as wheel speed increases.

12. A method according to Claim 11, in which the wind wheel drives four similar pumps at substantially equal speeds, of which three are by-passed at a first speed at the lower end of a given speed range, and none is by-passed at a second speed approximately twice the first speed at the upper end of the said speed range.

13. A method according to any one of Claims 1 to 12, in which energy obtained in excess of the maximum energy that can be absorbed by the generator means is dumped.

14. A method according to Claim 13, in which the excess energy is dumped through restricted hydraulic orifice means.

15. A method for electric power generation substantially as hereinbefore described with reference to the accompanying drawing.

16. Apparatus for use in electric power generation from wind energy comprising an accumulator for energy obtained from the wind in an intermediate form connectible to drive electric generator means, and control means for connecting said accumulator to drive said generator means when the amount of accumulated energy exceeds a predetermined value.

17. Apparatus according to Claim 16, in which said accumulator comprises an hydraulic piston-in-cylinder arrangement.

18. Apparatus according to Claim 17, in which said piston-in-cylinder arrangement is gravity loaded so that the output pressure thereof has a substantially constant value.

19. Apparatus according to Claim 17 or Claim 18, comprising piston actuated control means adapted to actuate hydraulic motor means driving said generator means.

20. Apparatus according to Claim 19, said control means comprising four position switch means actuating control valves for a low power hydraulic motor, a high power hydraulic motor and an hydraulic energy dumper so that at a first position of said switch means the motors and energy dumper are inoperative, at a second position the low power motor is operative, at a third position the high power motor is also operative, and at the fourth position, the hydraulic energy dumper is also operative.

21. Apparatus according to any one of Claims 17 to 20, comprising wind wheel driven hydraulic pump means connected to said piston-in-cylinder arrangement.

22. Apparatus according to Claim 21, said pump means being operable to have a torque roughly proportional to the square of the wind wheel speed.

23. Apparatus according to Claim 22, said pump means comprising a plurality of

pumps and by-pass means operable in accordance with the wind wheel speed so that at low wheel speeds only one pump is not-by-passed but at progressively higher speeds other pumps are brought on torque.

24. Apparatus according to Claim 23, comprising four similar pumps, of which three have by-pass valves and control means arranged to close the by-pass valves serially at progressively higher wind wheel speeds such that all three by-pass valves are closed at about twice the speed at which all three are open.

25. Apparatus according to any one of Claims 16 to 20, comprising a wind wheel.

26. Apparatus according to Claim 25, in which said wind wheel is a fixed pitch wind wheel.

27. Apparatus according to Claim 25 or Claim 26, in which said wind wheel is automatically orientated into the wind.

28. Apparatus according to any one of Claims 25 to 27, said wind wheel comprising flaps or spoilers and means automatically to extend or deploy the same to limit wheel speed in high winds.

29. Apparatus according to any one of Claims 25 to 28, comprising a brake and automatic means to apply the brake when the wind speed exceeds a predetermined safe limit.

30. Apparatus according to any one of Claims 16 to 29, comprising a mains energised induction generator adapted to be driven from said accumulator in phase and voltage alignment with the mains supply so that it can feed energy to or draw energy from the mains supply according to the varying demand of local load.

31. Apparatus according to Claim 30, said generator being of about 5 KW capacity.

32. Apparatus according to any one of Claims 16 to 31, comprising a self energised generator.

33. Apparatus according to Claim 32, said self energised generator being of about 25 to 30 KW capacity.

34. Apparatus for electric power generation from wind energy substantially at hereinbefore described with reference to the accompanying drawings.

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1514995 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale